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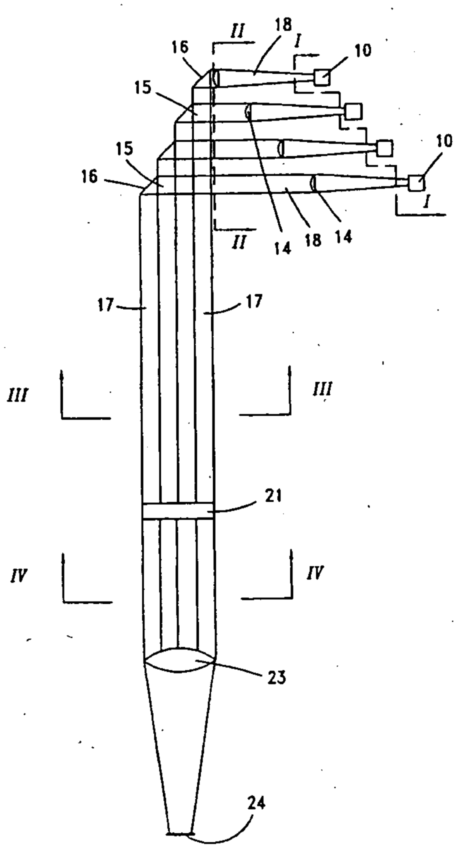
(54) Title: OPTICAL DEVICE FOR UNIFYING LIGHT BEAMS EMITTED BY SEVERAL LIGHT SOURCES



(57) Abstract: Light unifier that comprises a plurality of light sources (10) which emit parallel light beams of a rectangular cross-section, and a target area (24) onto which the light energy is focused. The unifier further comprises beam-shaping means (11), which comprises transverse collimators (14), means for juxtaposing the emitted beams to form a unified beam, a longitudinal collimator (21) for longitudinally collimating the unified beam, and means for focusing (23) the unified beam onto the target area.

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OPTICAL DEVICE FOR UNIFYING LIGHT BEAMS EMITTED BY SEVERAL LIGHT SOURCES

Field of the Invention

This invention relates to a device for unifying the light beams emitted by several light sources, in particular laser sources, and producing a unified beam which has the configuration defined by dimensions appropriate for illuminating small-sized targets, particularly for feeding into optical fibers, the unified beam having the highest brightness and having a desired, particularly a uniform, brightness distribution throughout its cross-section. The device of the invention has the highest optical yield, viz. highest ratio of optical energy transmitted to the target to the sum of the optical energies emitted by the light sources, and has the limited dimensions that are a requirement for devices of this kind.

Background of the Invention

The problem of unifying the light beams emitted by a plurality of light sources, particularly laser sources, has received considerable attention in the art. For instance, when optical fibers are used for transmitting light originating from several light sources, the problem arises of concentrating the beams emitted by said sources into a single beam that is small enough and has the appropriate cross-sectional shape for being introduced into an optical fiber without substantial loss of the globally emitted energy. The problem is complicated by the fact that the optical devices used for this purpose must have limited dimensions.

WO 92/02844 describes a High Power Light Source, comprising a number of laser diodes, wherein the laser beams are collimated by a lens, are

anamorphically expanded/reduced so that the width of each beam is in the x-axis is increased in relation to the width in the y-axis, and then are focused onto an optical fiber by a further lens.

WO 91/12641 describes a Solid State Laser Diode Light Source, which comprises at least two laser diodes, wherein the beams of the diodes are combined by a polarizing beam combiner and are focused by an length onto an optical fiber. The beams are acted on in the long direction of the laser stripes by anamorphic beam shaping means to reduce the length of the image formed at the end of the fiber.

PCT Patent Application WO 00/27002 describes a light-emitting adder allowing to obtain bright, integrated and substantially coherent light beam for illuminating a target area, either evenly or with increased brightness in the center of the illuminated spot, which adder comprises a plurality of light sources located in the same plane and beam-shaping means provided with beam-transporting means in order to form the resultant beam. Various ranges of optical lengths of the sources and wavelengths of the light emitted by the sources, as well as of degrees of beam mixing, are proposed therein.

It is a purpose of this invention to provide an optical device which fully achieves the results desired in this branch of the art, viz. unifies the beams emitted by different light sources, particularly laser sources, into a single beam with maximum optical yield, by "optical yield" being meant herein the ratio of the optical energy that is delivered to the target to the sum of the optical energies emitted by the several light sources.

It is another object of the invention to provide such a device which produces a beam that is adapted to be fed into an optical fiber.

It is a further purpose of the invention to provide such a device wherein the light sources are laser sources.

It is a still further object of this invention to provide such a device which has extremely limited dimensions.

It is a still further purpose of this invention to provide such a device which has a limited cost.

It is a still further purpose of this invention to provide a method for unifying the beams produced by several light sources, particularly laser sources, into a single beam with the highest optical yield.

It is a still further purpose of this invention to provide such a method for unifying beams of several light sources so as to produce a unified beam of high and uniform brightness.

Other purposes and advantages of this invention will appear as the description proceeds.

Summary of the Invention

The device of this invention comprises, as prior art devices comprise, a plurality of light sources, particularly laser sources, which emit parallel light beams of a rectangular cross-section, and a target area onto which the light energy is focused. By "beam cross-section" is meant the cross-section of a beam with a plane perpendicular to the direction of

propagation of the beam. Hereinafter, reference will be made to laser sources both for purposes of description and because they are the preferred light sources, but this should not be construed as a limitation, since the invention can be applied to light sources other than laser. In rectangular laser beams, the ratio of the long side of the rectangular cross-section to the short side is high, e.g., 20/1 or 120/1. Beams of such cross-section are produced by laser sources well known in the art, for instance SDL-6370-A, SDL-6380-A, SDL-6380-L-2, S-915-500C-50-x, S-915-1000C-100-x and S-915-1500C-150-x. For brevity's sake, the direction of the long side of the beam cross-section will be called hereinafter the longitudinal direction, and the direction of the short side will be called hereinafter the transverse direction. In a system of Cartesian coordinates, the X axis will be considered to be parallel to the longitudinal direction, the Y axis to the transverse direction, and the Z axis to the direction of propagation of the beam.

It is well known that the divergence of the laser beams in the transverse direction is much larger than the divergence in the longitudinal direction. Because of the divergence, the beams assume a frusto-pyramidal configuration, viz. they are bound by four slanted planes, two longitudinal and two transverse ones, each which makes an angle with one of the two planes of symmetry of the beams (one longitudinal and one transverse), the cross-section of which is the axis of propagation of the beam. The angle θa of each longitudinal slanted plane with the longitudinal axis of symmetry of the beam defines the longitudinal divergence, and the angle θb of each transverse slanted plane with the transverse axis of symmetry of the beam defines the transverse divergence, the ratio $\theta b/\theta a$ being larger than 1, e.g. 5.

According to the invention, the light unifier comprises, between the sources and the target area, a device that will be called “the beam-shaper” or “beam-shaping means”, which comprises the following components:

1 – means for collimating each of the several emitted beams in the transverse direction, hereinafter "transverse collimators";

2 – means for juxtaposing said beams to form what will be called “a unified beam”;

3 – means for imparting to the unified beam a square cross-section;

4 – means for collimating the unified beam in the longitudinal direction, hereinafter, "longitudinal collimator “, when the unified beam has been imparted a square cross-section; and

5 – means for focusing the collimated, unified beam onto the target area.

In addition to having a square cross-section, the unified beam should have the same divergence along all its sides, and the light unifier of the invention comprises means for imparting to the unified beam the same divergence along all its sides, as will be explained hereinafter.

According to the invention, the transverse collimators eliminate the transverse divergence of the individual beams. In order finally to obtain a square unified beam, they should be placed at such a distance from the sources that the sum of their transverse dimension equals the longitudinal dimension of the unified beam at the point at which it impinges on the longitudinal collimator. If the long and the short sides of the beams at the source are A and B respectively, and the beams travel paths of length d from the sources to the transverse collimators and paths of length D from said transverse collimators to said longitudinal collimator, their long

sides, when they impinge on said longitudinal collimator, will be $A+2(d+D)\mathrm{tang}\theta a$. The short side of each beam will be $B+2d\mathrm{tang}\theta b$. If there are "n" sources, the condition for imparting to the unified beam a square cross-section will be expressed by $A+2(d+D)\mathrm{tang}\theta a= n(B+2d\cdot \mathrm{tang}\theta b)$.

D+d is the optical length of the various beams minus the distance from the longitudinal collimator to the target area. For purposes of description, it will be called hereinafter "the primary optical length". It is a structural feature of the apparatus of the invention. If all optical lengths are equal for all the sources, the primary optical lengths are also equal. If the beam sides at the sources A and B, their divergence angles and the number n of source are given in a particular embodiment of the invention, the said formula will permit to calculate the position of the several transverse collimators. If there are differences between the optical lengths of different sources, the above formula permits to calculate the position of each transverse collimators. The condition for obtaining a square beam can be expressed verbally, as follows: the transverse collimators are placed at such a distance from the sources that the sum of the short sides of their beams at the point at which at which the beams reach the respective transverse collimators is equal to the long side of each of them at the point at which the beams reach the longitudinal collimator. If the transverse collimators do not annul the transverse divergences, the residual transverse divergences of the beams will cause a partial overlapping of the individual beams in the unified beam, which is not only possible, but even desirable. It will cause some transverse expansion of the individual beams before they are unified. Further, it will cause some transverse expansion of the unified beam. These expansions, generally minor ones, will not be

considered in the following description, but they can easily be accounted for by any expert persons to continue to satisfy the above condition.

As stated above, the unified beam should have the same divergence along all its sides. For this to occur, a condition that may be called "the equal divergence condition" should be satisfied. Said condition is expressed as

NA//beam = NA⊥beam ≤ NA fiber, (1)

where NA//beam = sinθa is the longitudinal numerical aperture of the emitted beam ;

NA⊥beam = sinθb is the transverse numerical aperture of the emitted beam ; and

NAfiber is the numerical aperture of a fiber.

The numerical apertures of the beam are related to the numerical apertures of the emitting body, designated hereinafter as NA//diode and NA⊥diode, wherein the use of the word "diode" to designated the emitting body is not to be construed as a limitation. Said emitting body apertures are respectively :

NA//diode (longitudinal numerical aperture of the emitting body) = sin θa

NA⊥diode (transverse numerical aperture of the emitting body) = sin θb

θa and θb are the half angles of divergence along the diode slow and fast axes, respectively. The beam numerical apertures are derived as follows.

According to the Lagrange-Helmhotz theorem,

A x NA//diode = H x NA//beam and (2)

B x NA⊥diode = h x NA⊥beam, (3)

where H is the long side (the length) of the unified beam at the longitudinal collimator; and h is the short side (the width) of the individual collimated beams making up the unified beam . A and B are, as

hereinbefore, the long and the short side, respectively, of the beams at the source.

Using formulae (1)-(3), we can write
H/h = A x NA//diode/(B x NA⊥diode) (4). This formula is valid if NA//beam = NA⊥beam, and this condition is achieved by suitable optical design, wherein the lengths of the collimators are chosen to equalize the aforesaid longitudinal and transverse numerical apertures.
Thus, the equal divergence condition defines the ratio of H to h.

Remembering that the long side of the beams, when they impinge on the longitudinal collimator, is A+2(d+D)tangθa and the short side is B+2dtangθb, we can write .
H = A + 2(d + D)tanθa and (5)
h = B + 2dtanθb. (6)

Since A and B are negligible in comparison with 2(d + D)tanθa and 2dtanθb, respectively, and d is small in comparison with D, equations (5) and (6) are approximated by
H = 2Dtanθa and (7)
h = 2dtanθb (8)

$$H/h = A \times NA\,//\text{diode} / (B \times NA\perp\text{ diode}) \qquad (4)$$

$$H = 2D\ tg\ \theta_a \qquad (7)$$

$$h = 2d\ tg\ \theta_b \qquad (8)$$

$$\frac{H}{h} = \frac{2D\ tg\ \theta_a}{2d\ tg\ \theta_b} = \frac{A \times NA\ //\text{ diode}}{B \times NA \perp \text{ diode}}$$

NA // diode = $\sin\theta_a$

NA $\perp$ diode = $\sin\theta_b$

$$\frac{D \quad \cos\theta_b}{d \quad \cos\theta_a} = \frac{A}{B}$$

Using (4), (7) and (8), we have

D/d = A cos θa/(B cosθb)

d/D = B cos θb/(A cosθa). (9)

F or example, A = 100 um, B = 1.3 um, d = 1.28 mm, D + d = 55.5 mm, θa = 6°, and θb ≅ 34°.

Equation (9) exhibits the relation between d and D. It is seen that they are interrelated. Thus, formulae (4) and (9) relate the parameters of the optical scheme to each other.

The condition of the squareness of the unified beam is

H = n h, (10)

where n is the number of individual beams (or, in other words, the number of laser diodes) making up the square unified beam.

This condition defines the number of laser diodes to achieve a square cross-section of the unified beam.

Formulae (10) and (4) give:

n = H/h = A x NA//diode/(B x NA⊥diode) = A sinθa/(B sinθb). (11)

Thus, the equal divergence condition in combination with the squareness condition defines the number of individual beams making up the unified beam. In other words, these conditions unambiguously define the number

of laser diodes used to achieve the unified beam with a square cross-section and the same divergence along the square sides.

The following particular example is given by way of illustration: Assuming as optical parameters:

A = 100 um, B = 1.3 um, NA//diode = 0.1, NA⊥diode = 0.55, θa = 6°, and θb ≅ 34°,

the number of diodes is

n = 100 um x 0.1/(1.3 um x 0.55) = 13.9 ≅ 14.

This means that only 14 beams can make up a unified square beam with the same divergence along its sides for the given optical parameters.

A deviation from said number may permit to obtain a unified beam that is rectangular rather than square and not with the same divergence along its sides concurrently.

The interrelation between the parameters of an emitting body and the SF optical scheme, on the one hand, and the parameters of an optical fiber, on the other, is now considered.

Inequality (1) relates the NAs of an emitting body to that of an optical fiber: NA//beam ≤ NAfiber, (1).

To equations (2) and (3), a term can be added representing a fiber:

A x NA//diode = H x NA//beam = k x Dfiber x NAfiber and (11)

B x NA⊥diode = h x NA⊥beam = k x Dfiber x NAfiber, (12)

In these equations Dfiber is the diameter of the fiber. NAfiber is the numerical aperture of the fiber, which aperture sinφ, wherein φ is the maximum half entrance angle, viz. the maximum angle from the fiber axis at which light beams can enter the fiber. k <1 is a coefficient taking into account the difference between the round fiber cross-section and the

square cross-section of the unified beam, which coefficient k should be as close to 1 as possible.

Formulae (1), (11) and (12) show the interrelation between the parameters of an emitting body and the optical parameters of the beam adder, on the one hand, and the parameters of the optical fiber onto which the unified beam is to be targeted, on the other.

The transverse collimators may be any suitable optical devices, for example, in their simplest form, cylindrical lenses the optical axis of which is parallel to the longitudinal direction of the beam which it collimates.

The means for juxtaposing the several individual light beams to form a unified beam – hereinafter, "the beam adder" – comprises means for deflecting the beams, preferably reflective means such as prisms or mirrors. It is preferred, but not necessary, that the deflection be by an angle of 90° and leave the beams parallel to one another. By effecting the deflection of different beams at suitable points along their path, the deflected beams are caused to become juxtaposed to one another. The beam deflectors are so located as to make the optical paths of the several beams as close as possible. Some differences in the lengths of the optical paths from beam to adjacent beam are tolerable, though it is desirable that they should not exceed 10%, and preferably, should not exceed 8% of said optical paths.

The longitudinal collimator may be any suitable optical device, but its simplest form is a cylindrical lens having its optical axis parallel to the transverse direction of the beams. It is such as to annul the longitudinal

divergence of the unified beam, so that said unified beam, which is square when it impinges on the longitudinal collimator, should remain square thereafter.

Finally, the focusing means may be constituted by any suitable optical device, but in the simplest form, are constituted by a spherical lens which concentrates the square, unified beam to a size depending on the size of the target and as equal as possible to it. If the target is an optical fiber, the focusing means will reduce the square cross-section of said unified beam so that it is inscribed in the round cross-section of the optical fiber, or said round cross-section is inscribed in said square cross-section, or said square and round cross-sections will overlap in most of their areas. In this way the loss of optical energy, due to portions of the unified beam falling outside the cross-section of the optical fiber, is minimized. If the target does not have a round cross-section, the focusing means will concentrate the unified beam in such a way as to minimize the loss of optical energy.

It is to be noted that the focusing means need not focus the unified beam directly onto the target. It focuses the unified beam onto a target area, and if the target is not in the target area, the focused beam may be transferred by any suitable optical device, without change of shape or size, or with such changes that may be desired in particular instances, from the target area to the target. Therefore, a distinction must be made between the target area, which is a geometrical element, and the target itself, which is a physical element.

The combination of transverse collimators, adder, longitudinal collimator and focusing means, are called collectively "beam-shaper" or

"beam-shaping means". Certain features of the beam-shaping means are essential: firstly, that the individual, emitted beams should be brought to juxtaposition or partial overlap, to form a square unified beam, before they are collimated in the longitudinal direction; and secondly, that the individual, emitted beams should be brought to juxtaposition or partial overlap, to form the unified beam, by deflecting them.

In a preferred aspect, the invention comprises a light unifier, having two groups of light sources which emit parallel light beams of a rectangular cross-section, and a target area onto which the light energy is focused, which two groups of light sources are symmetrical with respect to an axial plane. Each of said groups is provided with beam-shaping means, which comprises transverse collimators, beam deflectors and means for juxtaposing the deflected beams to form a partial unified beam. The transverse collimators, the juxtaposing mean, the beam deflectors and the two partial unified beams are symmetrical with respect to the axial plane. The partial unified beams become juxtaposed to form a unified beam. The light unifier further comprises a longitudinal collimator for longitudinally collimating the unified beam and means for focusing the unified beam onto the target area.

In an embodiment of said aspect of the invention, the light unifier produces two partial unified beams that are not juxtaposed, but leave a gap between them which is equal or almost equal to the transverse side of the deflected beams. The light unifier further comprises an additional light source and an additional transverse collimator having their axes on the axial plane of the unifier and producing an axial beam parallel to the deflected beams and inserted in said gap between the partial unified

beams. The unified beam is formed by the juxtaposition of said partial unified beams and said axial beam.

The invention therefore further comprises a method for forming a unified light beam from a plurality of individual, emitted beams, preferably laser beams, said individual beams having a rectangular cross-section in any plane perpendicular to the direction of propagation, which cross-section has a long (longitudinal) side and a short (transverse) side, and wherein the divergence in the transverse direction is higher than the divergence in the longitudinal direction, which method comprises:

a) collimating the beams in the transverse direction at a point at which the sum of the short sides of the beams is closer to and preferably slightly larger than their long sides,

b) thereafter, deviating them in such a way as to juxtapose them to form a unified beam;

c) thereafter, when the unified beam has assumed a square cross-section, collimating the same in the longitudinal direction, and

d) finally, focusing the unified, square beam onto the target area to attribute to it the desired final cross-section.

It should be stressed that the collimations need not be total, but may leave a certain degree of divergence, and skilled persons will know how to carry out the invention taking said residual degree of divergence into account. This should be understood as implied whenever collimation is mentioned.

Brief Description of the Drawings

In the drawings:

Fig. 1 is a schematic plan view of a light unifier according to a first embodiment of the invention;

Figs. 2a, 2b, 2C and 2d are schematic cross-sections of the beams shown in Fig. 1, taken on the planes indicated in Fig. 1 as I-I, II-II, III-III and IV-IV respectively; and

Fig. 3 is a schematic cross-sections illustrating a modification of the invention;

Fig. 4 is a schematic plan view of a light unifier according to a second embodiment of the invention; and

Fig. 5 is a schematic plan view of a light unifier according to a modification of the embodiment of Fig. 4.

Detailed Description of Preferred Embodiments

Fig. 1 is a plan view on a plane perpendicular to the long sides of the laser beams, viz. the Y-X plane. In Fig. 1 only four lasers are shown, but this is merely for the purpose of illustration, and in general the number of lasers will be higher, as desired in each case. The lasers, schematically indicated at 10, emit beams through rectangular openings 11, which have a long, longitudinal side of length A and a short, transverse side of length B. Fig. 2a, which is staggered a cross-section of the laser beams close to their emission (as indicated in said figure by the staggered trace I-I), can be interpreted as approximately illustrating the openings 11. In actual apparatus, as has been said, the length A of the longitudinal side is much higher than the length B of the transverse side, their ratio being, e.g., 100. Thus, A may be equal to 100 microns, while B may be equal to 1 micron. In the drawings, for purposes of illustration, the lengths of the sides is shown as quite different from what they would be in actual devices and their ratio is much lower than it would be.

The cross-section of each beam, at is emission, is equal to the openings 11. As the beams travel away from the sources, they diverge, viz. spread out, in segments 18, as shown in Fig. 1, until they impinge each on a transverse collimator 14, at which point they have larger transverse dimensions due to divergence, which they keep after the transverse collimation (assumed to be complete) as shown in Fig. 2b, a cross-section taken on plane II-II of Fig. 1. The transverse collimators are preferably cylindrical lenses, as schematically shown in the drawing, but may be different optical elements. They reduce the transverse divergence ideally to 0, as shown in Fig. 1, although in practice some transverse divergence may remain. Tranversely collimated beams 15 impinge on deflectors 16, which are schematically indicated as prisms, but may be any other suitable reflecting device, which deflect the beams by 90° to produce deflected beams 17. The position of the deflectors 16 is such that the deflected beams 17 are juxtaposed, as seen in Fig. 1, but preferably slightly overlapped. Thus means that in principle the deflectors are successively displaced parallel to the path of the collimated beams - each reflector with respect to the preceding one - by a distance equal to a short side of the beams, as clearly seen in Fig. 1; however, their displacement could be slightly shorter than said short side, whereby to cause adjacent beams to overlap by an amount not greater than 25%, or could be slightly longer, if the beams still retain some lateral divergence and therefore will spread out sufficiently to become juxtaposed. The short sides of the beams are such as to produce a unified beam 20 that will be square when it reaches longitudinal collimator 21, as will be explained hereinafter. The configuration of the unified beam when it is generated is shown in Fig. 2c, which shows a cross-section thereof taken on plane III-III of Fig. 1.

The cross-section of the unified beam, as in Fig. 2c, is still not exactly square, because its transverse side is slightly larger than its longitudinal side. It should be understood that the words "transverse" and "longitudinal", when referred to the unified beam have the same meaning as when they referred to the originally emitted beams, in spite of their deflection, viz. indicate directions respectively parallel to the short and to the long side of the individual beams.

As the unified beam 20 proceeds from it formation and from plane III-III, its long side will continue to diverge and expand, according to divergence θa, until it reaches longitudinal collimator 21, at which point its long side will have expanded to become equal to its short side, to produce a square cross-section 22, as illustrated in Fig. 2d, which is a cross-section taken on plane IV-IV of Fig. 1.

It will be noted, and is clearly seen in Fig. 2, that the paths traveled by the individual beams from the deflectors 16 to the longitudinal collimator 21 are different. In order to render the primary optical paths of the different beams equal, this difference must be compensated by an equal, but opposite, difference in the distances of the sources and of the transverse collimators 14 from the deflectors 16.

Longitudinal collimator 21 annuls the longitudinal divergence of the square, unified beam 22. The square, unified beam 22 now impinges on a focusing device 23, which is indicated in the drawings as a spherical lens, but may be any other suitable, and particularly more complex, optical device, which focuses beam 22 on the target area 24 and concentrates it to

such a size as may be convenient for introducing it into any small optical receiver or transmitter, such as an optical fiber. The concentrated unified beam will therefore have a side which is close to a corresponding dimension of the optical receiver, in the case of an optical fiber close to its diameter.

As has been said hereinbefore, if the actual physical target, e.g. an optical fiber, is not located in a target area, the unified beam will be transmitted by any suitable optical device, which may be called "a forwarding device", from the target area to the target.

As has been said, desirably, the laser sources and the transverse collimators will be so positioned that the differences in the distances that the beams travel from the source to the respective deflector compensate the differences in the distances traveled by the deflected beams, so that the optical paths of all the beams, viz. the distances between their sources and the target area, are ideally equal or differ from one another by small amounts.

As a purely illustrating numerical example, and assuming that both collimators annul the respective divergence, it will be assumed that the parameters defined hereinbefore have the following values:

$n = 10$

$A = 100\ \mu m$

$B = 1.3\ \mu m$

$A+2(d+D)\tan g\theta a = B+2d\tan g\theta b$

$\tan g\theta a = 0.1$

$\tan g\theta b = 0.67$

$D + d = 54.22$ mm.

Then, the condition A+2(d+D)tangθa= n(B+2d·tangθb) gives:

100 μm +2(55 mm)0.1 = 10(1.3 μm +2d·0.67) or 13.4· d = 11 mm + 87 = 11.987 mm;

d = 0.83 mm; and this is the distance at which the transverse collimators should be placed from the sources.

Since the individual beams, in this example, will have a transverse width of 1.3 μm = 2· D· 0.67 = 1.12 mm, the prisms, if prisms used to deflect the beams should have a slanted size of about 1.5 mm.

While the deflected beams 17 are shown in Fig. 1 to be exactly parallel and juxtaposed, the desired rectangular cross-section of the combined beam can be achieved by directing various beams, that are not exactly parallel and juxtaposed, by means of the deflectors 16 in such a way that they will become adjacent or partially overlapping when they impinge on the longitudinal collimator 21. Fig. 3 schematically-illustrates a variation of Fig. 2d in which a unified beam 25 comprises the partly overlapping individual beams, the overlapping areas being indicated by cross-hatching.

The combination of light sources, transverse collimators and beam juxtaposing means – which may be called, for brevity's sake, "unified-beam former" – may be effected more than once in a light unifier according to the invention, to produce a more powerful unified beam. An example is illustrated in Fig. 4, wherein longitudinal collimator 31, focusing means 32 and target area 33 are common to two unified-beam formers, which are generally indicated at 30 and 30' and are symmetrical with respect to an axial plane of the light unifier. Each of the two

symmetrical unified-beam formers comprises transverse collimators and beam deflectors, symmetrical with respect to said axial plane, and having the same features that have been described with respect to the collimators and deflectors of Fig. 1. It may be said that such a light unifier is constituted by two light unifiers as described with reference to Fig. 1, disposed symmetrically with respect to an axial plane. In Fig. 4, the elements corresponding to those of Fig. 1 are indicated by the same numerals for beam former 30 and by corresponding accented numerals for former 30'.

Fig. 5 illustrates such an apparatus, which however is further improved by providing a central laser source 35 with its transverse collimator 36, all coaxial to the axial plane of the apparatus, viz. the plane of symmetry of the two unified-beam formers 30-30'. The beam of source 35 can propagate directly to collimator 31 without undergoing deflection. The only condition is that the central source be so placed as to have the same or nearly the same optical length as the other sources, the beams of which have been deflected. Preferably, the difference in optical length ΔL between laser diodes of a pair placed symmetrically wit respect to the adder optical axis should meet the coherence requirement $\Delta L \leq \pi\lambda^2 / 8\ \delta\lambda$, wherein λ is the wavelength of a laser diode and $\delta\lambda$ is the deviation of the wavelength.

In the combination of two unified-beam formers illustrated in Fig. 4, all the laser sources are located on the same plane. It will be appreciated that small deviations from said plane are permissible and can be compensated by suitably slanting the reflecting beams.

However, it is possible to combine two unified-beam formers (indicated hereinafter as "SFs") which are not coplanar, viz. wherein the laser sources of one such former are located in a different planes from those of the other such former, the two planes making an angle preferably of 90°. Even in this case, the longitudinal collimator, the focusing means, and the target area are common.

The radiation of a laser diode is known to be strongly polarized. The polarization plane of the unified beam of the left SF should be perpendicular to that of the bottom SF. A polarizer transmits the unified beam of the left SF and completely reflects the unified beam of the bottom SF.

Thus, we create a total beam after polarizer that has two perpendicular polarization planes and is made up of the two unified perpendicular beams of two SFs.

Preferred kinds and sizes of the unifier components are as follows:

Laser sources: 6.5 x 8 mm C-mount package.

Emitting body: A = 100 um, B = 1.3 um, NA//diode = 0.1, NA⊥diode = 0.55, θa = 6°, and θb ≅ 34°.

Transverse collimators: focal distance F = 1.28 mm, ∅ = 8 mm, h = 8 mm.

Reflecting means: 55 x 27 x 22 mm, facet = 1.5 mm.

Longitudinal collimators: 14 x 14 mm, F = 55.5 mm.

Focusing means: ∅ = 13 mm, 1 = 20 mm, F = 25 mm.

Cross-section of the focused, unified beam: 12 x 13.3-mm collimated beam and 40 x 42-μm focused beam at the target area.

While embodiments of the invention have been described by way of illustration, it will be apparent that the invention may be carried out with many modifications, variations and adaptations, without departing from its spirit or exceeding the scope of the claims.

CLAIMS

1. Light unifier, having a plurality of light sources which emit parallel light beams of a rectangular cross-section, and a target area onto which the light energy is focused, characterized in that it further comprises beam-shaping means, which comprises transverse collimators, means for juxtaposing the emitted beams to form a unified beam, a longitudinal collimator for longitudinally collimating said unified beam, and means for focusing said unified beam onto said target area.

2. Light unifier according to claim 1, wherein the light sources are laser sources.

3. Light adder according to claim 1, wherein the light beams cross-section has a long, longitudinal side and a short, transverse side, and the ratio of the longitudinal side to the transverse side is from 20 to 120.

4. Light unifier according to claim 1, wherein the beam-shaping means comprise:

A – transverse collimators;

B – a beam adder for juxtaposing the beams to form a unified beam;

C – means for imparting to the unified beam a square cross-section;

D – a longitudinal collimator, located at a point at which the unified beam has been imparted a square cross-section; and

E – means for focusing the collimated, unified beam onto the target area.

5. Light unifier according to claim 4, wherein the transverse collimators are placed at such a distance from the sources that the sum of the short sides of the beams at the point at which at which the beams reach the respective transverse collimators is equal to the long side of each of them at the point at which the beams reach the longitudinal collimator.

6. Light unifier according to claim 4, wherein the beam adder comprises means for deflecting the beams.

7. Light unifier according to claim 6, wherein the means for deflecting the beams are reflective mean.

8. Light unifier according to claim 6, wherein the means for deflecting the beams are as to produce a deflection by an angle of 90° and to leave the beams parallel to one another.

9. Light unifier according to claim 4, wherein the beam adders are so located as to make the optical paths of the several beams as close as possible.

10. Light unifier according to claim 4, further comprising means for transferring the focused, unified beam from the target area to a target spaced therefrom.

11. Light unifier according to claim 1, wherein the beam-shaping means are such as to bringing the individual, emitted beams to juxtaposition or

partial overlap, to form a square unified beam, before they are collimated in the longitudinal direction, and as to bring the individual, emitted beams to juxtaposition or partial overlap, to form the unified beam, by deflecting them.

12. Light unifier according to claim 7, wherein the reflecting means are chosen from among prisms and mirrors.

13. Light unifier according to claim 4, wherein the deflecting means are such and so positioned as to cause the deflected beams to overlap to an extent not exceeding 25% of the cross-sectional area of any one of the overlapping beams.

14. Light unifier, having two groups of light sources which emit parallel light beams of a rectangular cross-section, and a target area onto which the light energy is focused, characterized in that said two groups of light sources are symmetrical with respect to an axial plane, and each is provided with beam-shaping means, which comprises transverse collimators, beam deflectors and means for juxtaposing the deflected beams to form a partial unified beam, said transverse collimators, said juxtaposing mean, said beam deflectors and said two partial unified beams being symmetrical with respect to said axial plane and said partial unified beams being juxtaposed to form a unified beam, said light unifier further comprising a longitudinal collimator for longitudinally collimating said unified beam and means for focusing said unified beam onto said target area.

15. Light unifier according to claim 14, wherein the two partial unified beams are not juxtaposed and which further comprises an additional light source and an additional transverse collimator having their axes on the axial plane of the unifier and producing an axial beam parallel to the deflected beams and inserted between the partial unified beams, a unified beam being formed by the juxtaposition of said partial unified beams and said axial beam.

16. Light unifier according to claim 1, having a number of light sources such as to permit to obtain a unified beam that has a square cross-section and the same divergence on all its sides.

17. Light unifier according to claim 1, having a number of light sources is $n = A\sin\theta a / B\sin\theta b$, wherein A and b are the long and short side, respectively, and θa and θb are the longitudinal and transverse aperture angles, respectively, of the emitted beams.

18. Method for forming a unified light beam from a plurality of individual, emitted beams, preferably laser beams, said individual beams having a rectangular cross-section in any plane perpendicular to the direction of propagation, which cross-section has a long (longitudinal) side and a short (transverse) side, and wherein the divergence in the transverse direction is higher than the divergence in the longitudinal direction, which method comprises:

a) collimating the beams in the transverse direction at a point at which the sum of the short sides of the beams is closer to and preferably slightly larger than their long sides,

b) thereafter, deflecting them in such a way as to juxtapose them to form a unified beam;

c) thereafter, when the unified beam has assumed a square cross-section, collimating the same in the longitudinal direction, and

d) finally, focusing the unified, square beam onto the target area to attribute to it the desired final cross-section.

19. Method according to claim 18, further comprising causing the unified beam to have the same divergence on all its sides.

20. Light unifier, substantially as described and illustrated.

21. Method for forming a unified light beam from a plurality of individual, emitted beams substantially as described and illustrated.

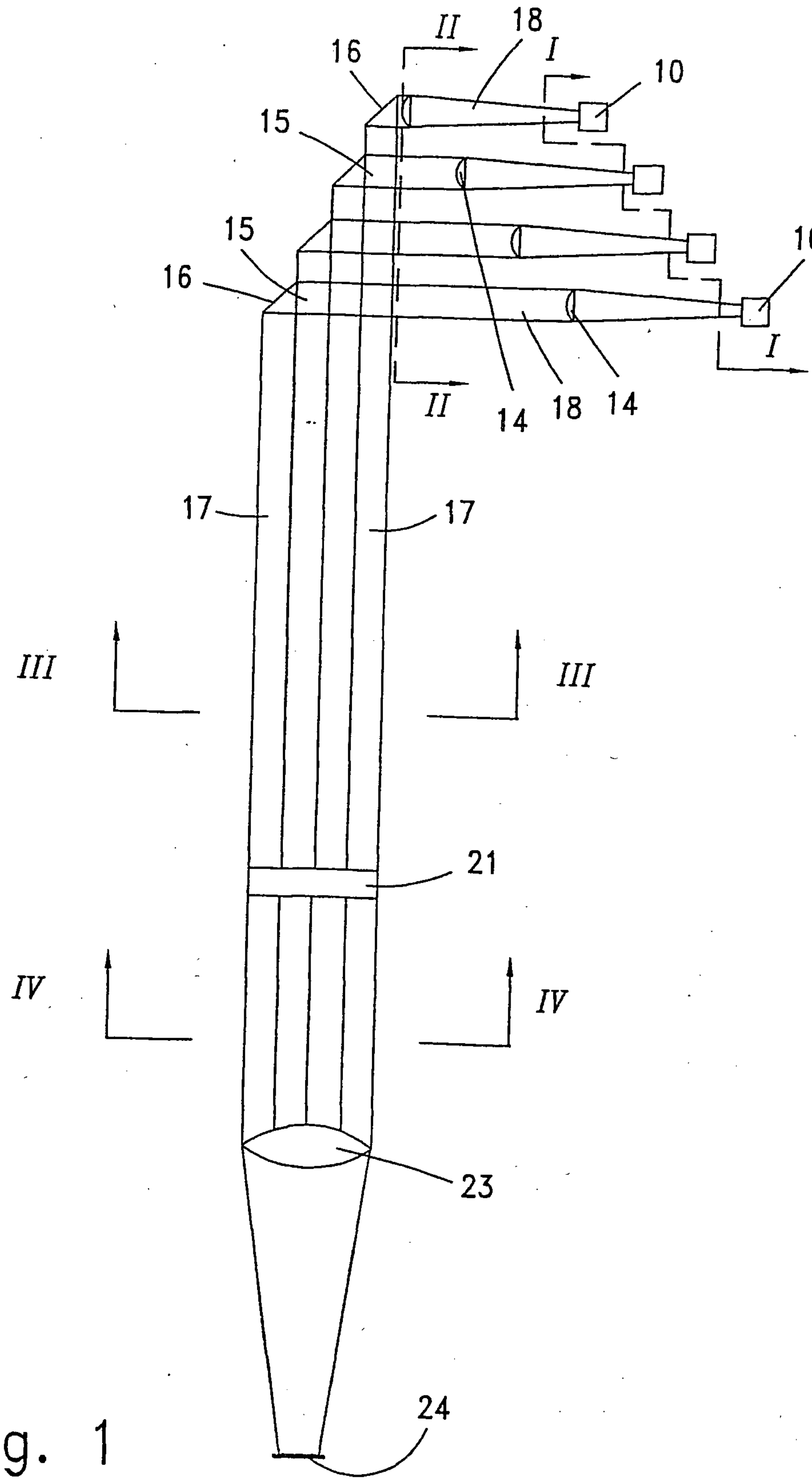

Fig. 1

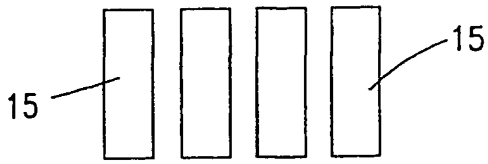

Fig. 2b

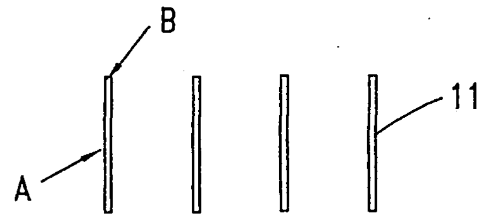

Fig. 2a

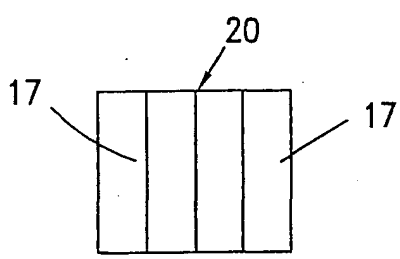

Fig. 2c

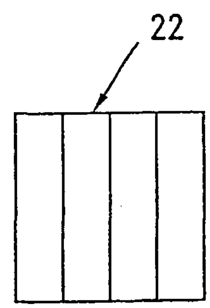

Fig. 2d

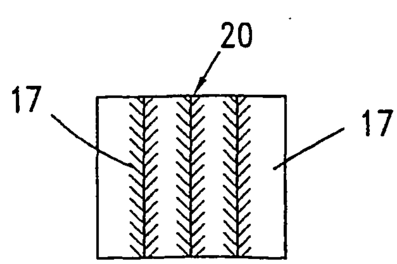

Fig. 3

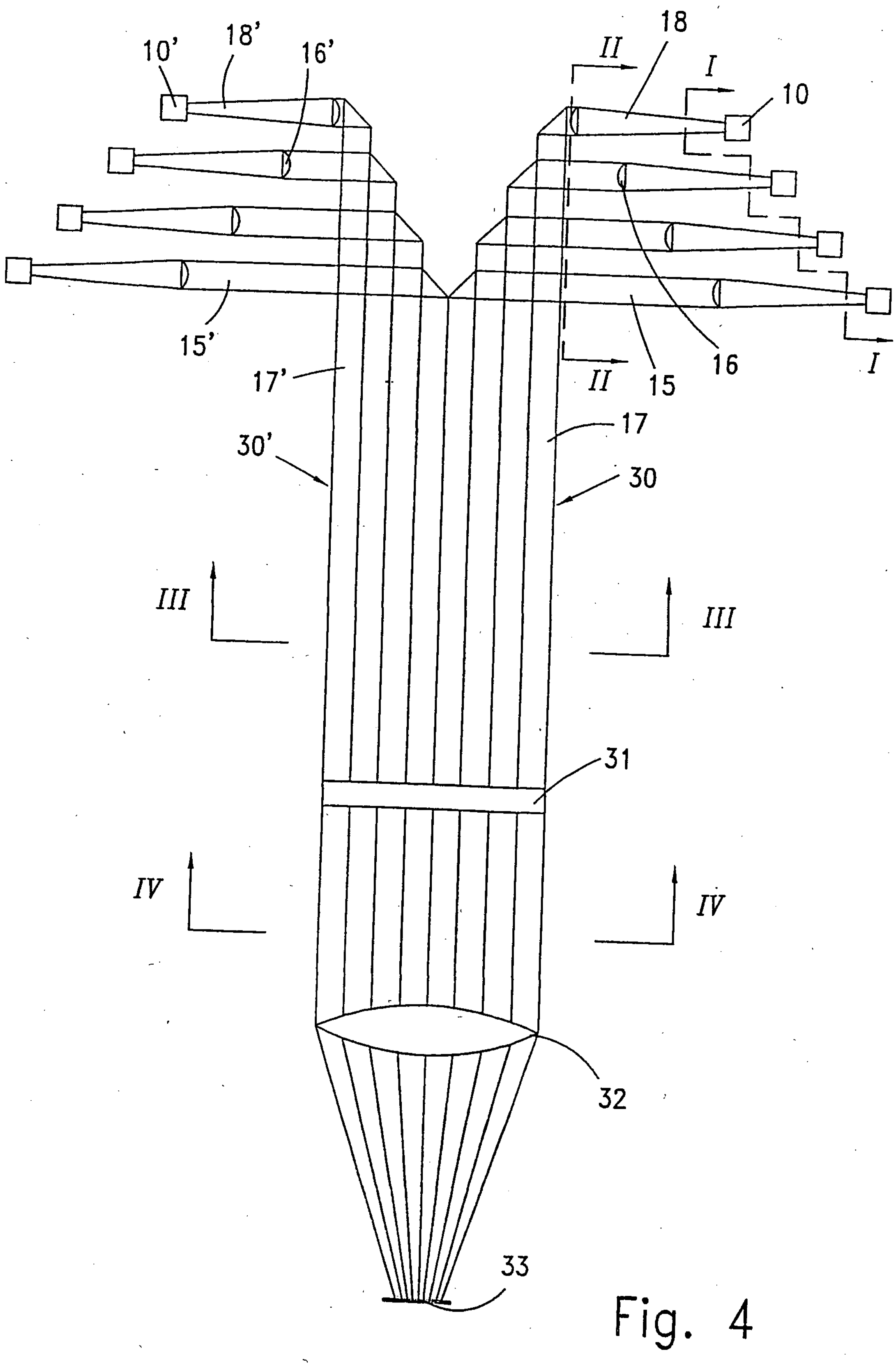

Fig. 4

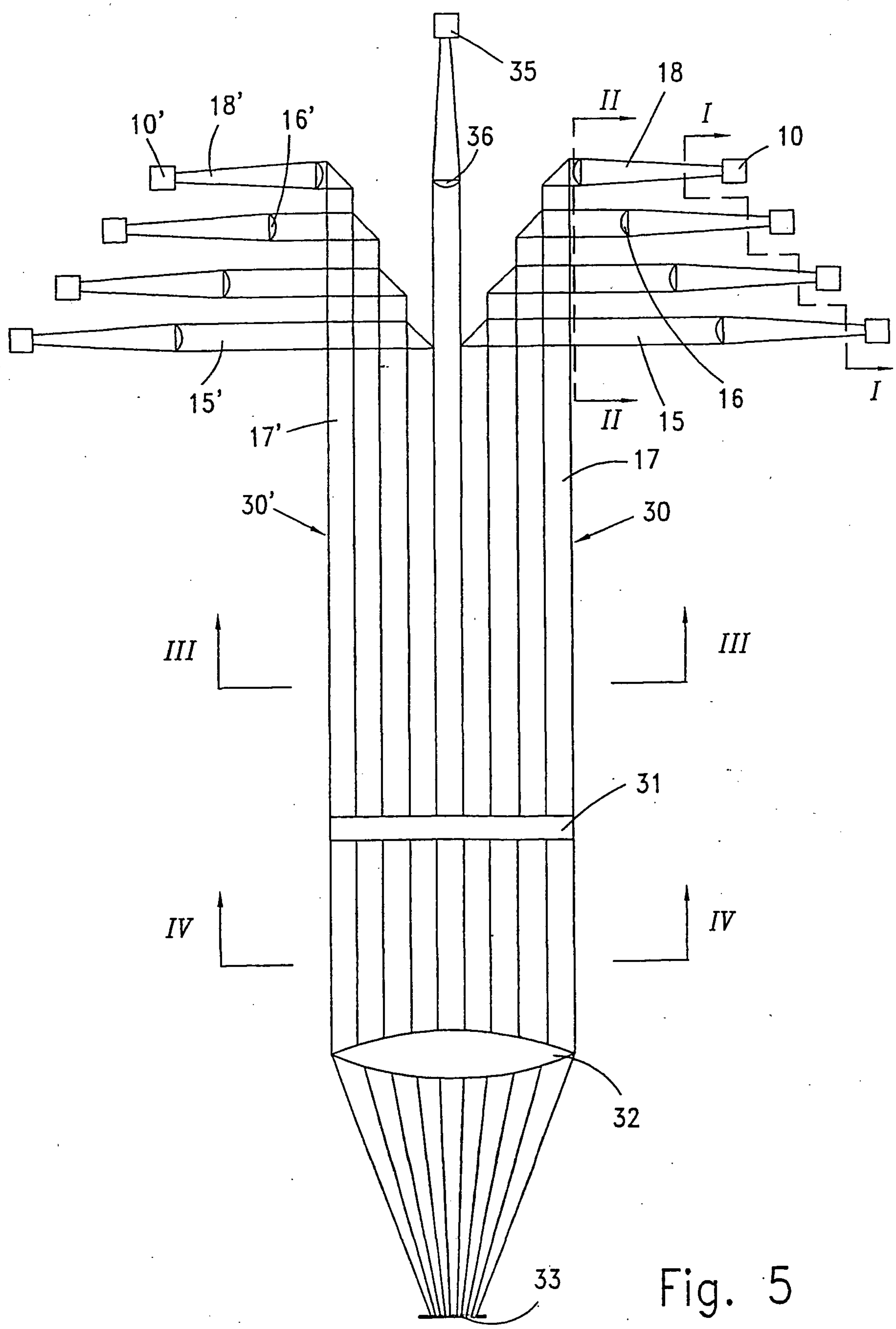

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IL01/01174

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :G02B 27/10, 27/30
US CL :359/618, 641

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 359/618, 641

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
USPAT, JPO, EPO, Derwent, IBMTDB
search terms: collimat$, beam-shaping or (beam$1 near3 shap$3), focus$3

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A, P	US 6,254,287 B1 (GROETSCH et al.) 03 July 2001 (03.07.2001).	1-21

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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Date of the actual completion of the international search
06 MAY 2002

Date of mailing of the international search report
07 JUN 2002

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